



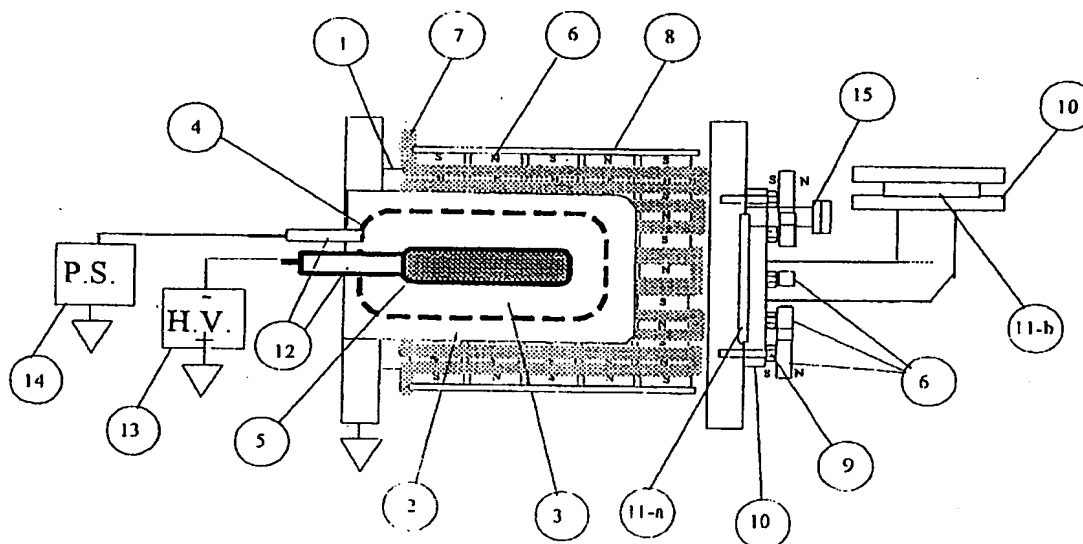
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(54) **IMPLANTATION D'IONS MONOENERGETIQUES DE  
DISTRIBUTION UNIFORME**

(54) **UNIFORM DISTRIBUTION MONOENERGETIC ION  
IMPLANTATION**



(57) A system for implanting ions in an object which has three dimensional topology in a uniform or predetermined pattern is provided by the invention herein. The system includes a vacuum chamber defining an interior space. The interior space includes a first region adjacent to interior walls of the vacuum chamber. The first region being used primarily for plasma protection. The interior space of the vacuum chamber also includes a second region for ion acceleration and the second region is substantially surrounded by the first region. A potential distribution control grid defines the boundary between the first and second regions and the potential distribution control grid is pervious to the passage of ions from the plasma generated in the first region into the second region. An object to be implanted is placed at a predetermined position in the second region and when subjected to a negative voltage charge, draws ions through the potential distribution control grid from the first region into the second region and accelerates them in a uniform manner towards the object to be implanted. The accelerated ions are monoenergetic since they all have the same momentum. The system provides magnetic field to help confine the plasma in the first region but maintains the second region in a relatively magnetic field free state.



## ABSTRACT OF THE DISCLOSURE

A system for implanting ions in an object which has three dimensional topology in a uniform or predetermined pattern is provided by the invention herein. The system includes a vacuum chamber defining an interior space. The interior space includes a first region adjacent to interior walls of the vacuum chamber. The first region being used primarily for plasma protection. The interior space of the vacuum chamber also includes a second region for ion acceleration and the second region is substantially surrounded by the first region. A potential distribution control grid defines the boundary between the first and second regions and the potential distribution control grid is pervious to the passage of ions from the plasma generated in the first region into the second region. An object to be implanted is placed at a predetermined position in the second region and when subjected to a negative voltage charge, draws ions through the potential distribution control grid from the first region into the second region and accelerates them in a uniform manner towards the object to be implanted. The accelerated ions are monoenergetic since they all have the same momentum. The system provides magnetic field to help confine the plasma in the first region but maintains the second region in a relatively magnetic field free state.

## UNIFORM DISTRIBUTION MONOENERGETIC ION IMPLANTATION

### FIELD OF THE INVENTION

The present invention relates to ion implantation of an object to create certain surface characteristics. More particularly, it relates to a method and apparatus to implant ions in an object in a predetermined pattern, said object having three dimensional (3-D) topology.

### BACKGROUND OF THE INVENTION

At present, conventional ion beam source implantation methods and systems are used to implant energetic particles into the surface (near surface) of an object selected for ion beam implantation. Ion energy levels determine the depth of ion implantation in the object. Conventional ion beam source methods and systems generate the ions from a plasma source and then use an extraction - acceleration grid assembly to extract and accelerate the ions toward the object selected for implantation. However, these methods rely on grids which have plane geometry and are located outside the source. As a result, all extracted ions travel in the same direction with little divergence.

More recently, plasma source ion implantation (PSII) methods and systems have also been proposed as a solution for implanting energetic ions into the surface of objects with 3D surface topology. In PSII a plasma is produced in a vacuum chamber, the object is immersed into the plasma, and then the object is submitted to repetitive short, negative, high voltage pulses. Each negative voltage pulse repels the electrons from the vicinity of the surface, and accelerate the ions toward the surface of the object undergoing ion implantation.

Conventional Ion beam methods and systems are used extensively in the microelectronic industry for semiconductor doping. Conventional ion beam methods and systems, because they are unidirectional have limited industrial applications outside the microelectronics industry. The microelectronics industry generally only has to be concerned with implanting ions in the flat planar surfaces of chips. Most other technologies which can use ion implantation, including the biomedical field, deal with

objects that have 3-D topologies such as artificial joints , stents used in angioplasty etc. Most of these applications require a precise implantation of ions in uniform and predetermined patterns generally at precise concentrations and depths of implantation. In order to achieve these requirements of precise concentrations and depths of ion  
5 implantation on objects with 3D topology current methods and systems rely on complicated manipulation of objects in vacuum. Masking of object also becomes necessary to control the uniformity of implantation, since the sputtering rates of materials has strong dependence to the angle of incident ions.

Plasma source ion implantation allows 3D implantation, however, it has three  
10 main disadvantages: (i) an object under implantation is immersed into the plasma, during the pause between the implantation periods (between voltage pulses), the interactions between the background plasma and the surface implanted can change the surface properties (e.g. erode the surface); (ii) Since the voltage pulse shape determines the energy of the particles implanted and inevitably particles with energies ranging from few  
15 eV to that determined by maximum applied electric potential are implanted into the object; (iii) the extraction surface is determined by the plasma sheath front, and the plasma sheath front expands during the voltage pulse, there is no control over uniformity (or non uniformity) of the implanted surface. The term sheath front corresponds to the boundary between the region where electrons are repelled (also called ion matrix) and the  
20 plasma.

#### SUMMARY

The invention uses a  $4\pi$  steradian concept which allows the implantation of monoenergetic ions into a three dimensional surface, in the absence of plasma surface  
25 interaction. In its simplest form, the  $4\pi$  steradian concept has a single extraction grid ion beam source that surrounds the target. The object to be implanted is biased to a high negative DC voltage, and is surrounded by a highly transparent control grid that defines an equi-potential surface. The ions are supplied from a pulsed or a DC plasma, localized between the control grid and the implanter wall. The ions that traverse the grid are  
30 extracted, accelerated and imparted into the surface of the object to be implanted with

energies determined by the biasing voltage and the ion charge state.

Thus, in one aspect, the invention provides an apparatus for implanting ions in a predetermined pattern into an object, which object has a 3-D topology. The invention provides a vacuum chamber which defines an interior space. The interior space of the vacuum chamber includes a first region adjacent to the interior walls of the vacuum chamber. The first region is used primarily for plasma production. The interior space includes a second region for ion acceleration and the second region is substantially surrounded by the first region. A potential distribution control grid defines the boundary between the first and second region. The potential distribution control grid being pervious to passage of ions such that when an object to be implanted with ions is placed at a predetermined position within the second region and is subjected to an negative voltage potential, ions from the plasma generated in the first region pass through the potential distribution control grid and are uniformly accelerated towards the object to be implanted so that all ions drawn through the potential grid are monoenergetic, having the same momentum and are directed towards the object to be implanted.

In the preferred embodiment, the potential distribution grid is held at a constant potential, i.e. ground and the object to be implanted is subjected to a large negative DC voltage to draw ions from the first region into the second region and accelerate them in a constant manner towards the object to be implanted.

However, in an alternative aspect, the potential distribution control grid can have its voltage varied to either block the passage of ions through it into the second region or to conversely facilitate the injection of the ions into the second region and their acceleration towards the object to be implanted.

In one aspect of the invention, the potential distribution control grid is a mesh with a multitude of openings. The openings being sized to allow the passage of ions therethrough, but being of sufficiently small size to prevent the passage of radiation through which may be used in the first region to generate a plasma, said radiation potentially being microwave radiation.

In another aspect of the invention, the ions are drawn into the second region in a predetermined pattern which provides for uniform distribution of the ions over the

surface of the object or target being implanted.

In another aspect of the invention, it maintains the second region free of magnetic fields.

The invention also provides a method for implanting ions in a predetermined pattern in an object with three dimensional topology. The method consisting of the steps of generating a plasma in a first region, said first region substantially surrounding a second region, then injecting the ions from the plasma in the first region into the second region and accelerating those ions in a uniform manner towards an object located at a predetermined position in the second region. The ions being accelerated in a uniform manner such that they all have the same momentum and are thus monoenergetic.

In another aspect of the method of this invention, the step of injecting ions into the second region and accelerating them towards the object to be implanted comprises subjecting the object to be implanted with ions to a negative DC voltage.

In yet another aspect of the method of this invention, it includes the step assuring that the second region remains free of magnetic fields.

In yet another aspect of the method of this invention, the steps of implanting the ions in the object in a predetermined pattern involves uniformly distributing the implanted ions in the object.

In yet another aspect of the method of this invention, when microwave radiation is used to generate a plasma in the first region, steps are taken to prevent the migration of the microwave radiation into the second region and thus avoid the creation of a plasma in the second region. In the preferred embodiment, the step of preventing the migration of microwave radiation used to generate a plasma in the first region into the second region consists of providing a mesh barrier with a multitude of openings large enough to allow ions to pass therethrough but small enough to prevent the penetration of the microwave radiation into the second region.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood by an examination of the following description, together with the accompanying drawings, in which:

Fig. 1 provides a basic schematic view of the major functional components of the present invention;

Fig. 2 provides a partial cut away schematic view of a detailed embodiment of the present invention; and

5 Fig. 3 is view of an exterior side of the vacuum chamber of the present invention showing the arrangement of a microwave flange bolted to the chamber.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

##### 10 Overview:

The schematic diagram of the 3-D Ion Implanter (3DII) is shown in Fig.1. 3DII has a vacuum chamber 1 evacuated to a base pressure below  $10^{-7}$  torr. The chamber 1 is made of a conducting material. The Implanter has two distinct regions. Plasma production region (PPR) 2 and the ion acceleration region (IAR) 3. The boundary  
15 between these two regions is defined by a potential distribution control grid (PDCG) 4. The potential distribution control grid has an important influence on the distribution of the implanted ion dose. PDCG 4 defines an equipotential surface, and in the case of plasma production by microwaves (or rf ) the grid prevents microwave (rf) field penetration into IAR 3. The target to be implanted 5 is placed inside the IAR 3, and is  
20 connected to a negative high voltage. On the target, the implanted ion dose distribution is affected by the uniformity of ion (plasma) density near PDCG 4 at PPR 2, and the potential distribution in IAR 3. Ion production in IAR 3 must be negligible (to prevent broadening of the implanted ion energy distribution), and collisions between ions and neutrals in IAR 3 must be rare, in other words the ion neutral collision mean free path in  
25 IAR 3 must be much longer than the distance between the target and the PDCG 4 (to avoid slowing down of ions, and prevent broadening of the implanted ion energy distribution). To avoid changing ion trajectories, the magnetic field intensity in IAR 3 must be negligible. The plasma interaction with the target 5 must be negligible, in order to avoid altering the surface properties by low energy ion bombardment.

30 For a given operating pressure in the chamber, the distance between target 5 and

the grid 4 must be large enough to avoid arcing between the target 5 and PDCG 4; however, the distance should be such that a glow discharge in IAR 3 is not initiated. For implantation of ions from a gaseous source, the gas (or a mixture of gases) is injected directly into the chamber.

5 For implantation of ions from solid (or liquid) elements, sputtered or (evaporated) particles can be injected into the chamber and ionized subsequently, either directly or by a buffer plasma. The buffer plasma can be Ar, He or any other noble gas. If deposition (and ion mixing) is to be avoided then no direct line of sight should exist between the target and the metallic particle source.

10 For implantation of nonconducting (or conducting) solid elements, one can also use a crucible to evaporate the element, or one can use magnetron sputtering.

#### Detailed Description of 3DII:

The schematic of the prototype 3-D Ion Implanter (3DII) is shown in Figs. 2 and  
 15 3. The vacuum chamber 1 is evacuated to a base pressure below  $10^{-7}$  torr. The chamber 1 is made of a conducting, but non magnetic material, and it is held at ground potential. In our prototype, we have used a stainless steel cylindrical chamber which has a 10-cm inner diameter and is 22-cm long, though the chamber can have a different shape. The chamber is initially pumped down to below  $10^{-7}$  torr, and then it is filled with an  
 20 operating gas (or a mixture depending upon the intended application).

The plasma in PPR 2 can be produced using different methods, however, to reduce the impurities in the plasma, electrodeless methods have a distinct advantage. We use microwave discharge method to produce a substantially uniform plasma in PPR 2. The plasma in PPR 2 near PDCG 4 should be substantially uniform to simplify the  
 25 control of the implanted ion dose distribution.

Magnetic fields can substantially improve the particle confinement, and hence increase the efficiency of the plasma production process. However, the magnetic field intensity in IAR 3 must be negligible to avoid influencing ion trajectories that bombard the target, and to prevent electron trapping that can result in plasma production in IAR  
 30 3. Permanent magnets have the advantage that they can be used to engineer complicated



magnetic field topologies. Sixteen rows of permanent magnets 6 are placed on the outer wall of the chamber, there are six permanent magnets in each row, arranged in alternating poles. We use a checkerboard configuration, since the magnetic field intensity drops off much faster as the order of multipoles increases. This design allows one to keep the magnetic field intensity in the IAR 3 to a negligible level. If the permanent magnets can produce a magnetic field in the PPR 2 region that is perpendicular to the microwave electric field, and has an intensity equal to  $B = 2Bmf\mu W/e$  (where  $e$  and  $m$  are electron charge and mass, and  $f\mu W$  is the microwave frequency), then ionizing the gas with electron cyclotron resonance (ECR) coupling becomes possible. This scheme is particularly attractive, and is efficient for plasma production at low pressure ranges (10-5 - 10-4 torr range), where conventional microwave cavity discharges are less efficient.

The preferred embodiment uses microwaves at 2.45 GHz, and the field intensity for ECR coupling is 875 G. Such field intensity can readily be produced with NdFeB (used in our prototype) and other rare earth permanent magnets. In the prototype the resonance zones are about 1.0 cm from the wall. The permanent magnets are kept near room temperature to ensure that they retain their magnetization. Each row of permanent magnets is sandwiched between two water cooling copper tubes 7. The tubes are brazed to the plasma chamber, and the heat transfer between the copper tubes and the magnets is enhanced using a thermic paste.

A temperature sensor is used to monitor the temperature of the plasma chamber. The soft iron layer 8 acts as return winding for the magnetic field. Eight iron screws 9, which bolt down the microwave flange 10 to the source chamber, are also used to transfer the magnetic flux from the magnets installed on the surface of the flange to the interior of the plasma chamber. A quartz window 11-a provides the vacuum seal between the plasma chamber and the microwave waveguide. The window is placed in a different location 11b if there is a possibility of depositing material on the window. Instead of quartz window, any other low loss material, suitable for vacuum sealing, can also be used. Microwaves can also be introduced into the chamber 1 by an antenna.

The PDCG 4 is made of a partially transparent conductor (mesh), the mesh size should be small enough to prevent substantial microwave penetration into IAR 3. In the

prototype the mesh is made of stainless steel, with a spacing of 0.1 cm and about 60% transparency. However, any conducting mesh with somewhat different spacing and transparency can also be used, provided the spacing remains small compared to the microwave wavelength. PDCG 4 is also connected to a H.V. feedthrough 12, so it can be  
5 biased using an independent power supply 14. Biasing PDCG 4 in turn will enhance the extracted ion current from PPR 2; however, biasing PDCG 4 will enhance sputtering from its surface. If the presence of these sputtered particles are not tolerated on the target 5, then the PDCG 4 must be kept at ground potential. The working gas can be introduced into the chamber via small port 15 and a control valve. The same port can be used to  
10 introduce material by evaporation.

The target to be implanted 5 is placed inside the IAR 3, and is connected to a negative high voltage 13 via a high voltage feedthrough 12. Ion production in IAR 3 must be negligible, and the ion neutral collision mean free path must be much longer than the distance between the target and the PDCG 4, otherwise the ion neutral collisions will  
15 slow down the ions, and will broaden the ion energy distribution. There are three important factors to be considered in determining the distance between the target 5 and PDCG 4. The distance should be large enough to avoid arcing, but kept small enough to increase the extracted current (increase the flux), and avoid creating a glow discharge in IAR 3. The operating pressure in the prototype implanter has been below 1 mtorr, and the  
20 maximum negative voltage applied to the target has been - 35 kV. A 1.0 cm gap between the target 5 and PDCG 4 has proved to be an appropriate compromise.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and detail may be made to it without departing from the spirit  
25 and scope of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:-

1. A system for implanting ions in an object with 3-D topology in a uniform pattern, said system comprising:

a vacuum chamber defining an interior space;

a potential distribution control grid within the vacuum chamber which divides the vacuum chamber into a first region for plasma production, said first region being located between interior walls of the vacuum chamber and an outside surface of the potential distribution control grid, and a second region for ion acceleration, the shape of the potential distribution control grid being such that it entirely encloses the second region for ion acceleration and shields it from the first region;

said potential distribution control grid being permeable to passage of ions when an object, with 3-D topology, is positioned in the second region at a predetermined location and said object is subjected to a negative voltage potential.

2. An apparatus for implanting ions in a predetermined pattern in an object, which object has 3-D topology, said apparatus comprises:

a vacuum chamber defining an interior space;

said interior space includes a first region adjacent to interior walls of the vacuum chamber, said first region being primarily used for plasma production;

said interior space of said vacuum chamber includes a second region for ion acceleration, said second region being substantially surrounded by the first region;

a potential distribution control grid which defines a boundary between the first and second regions, said potential distribution control grid being pervious to passage of ions such that when an object is placed within the second region at a predetermined position and subjected to a negative voltage potential, ions are drawn through the potential distribution control grid into the second region and uniformly accelerated towards the object such that all of the ions drawn through the potential distribution control grid are monoenergetic.

3. The apparatus of claim 2, wherein the potential distribution control grid is a mesh with a plurality of openings through which ions can pass but which are of sufficiently small size to block passage of radiation used to turn material in the first region into a plasma.
4. The apparatus of claim 2, wherein the radiation used to turn material in the first region into a plasma is microwave radiation.
5. A method for implanting ions in an object, said object having three dimensional topology, said method comprising:

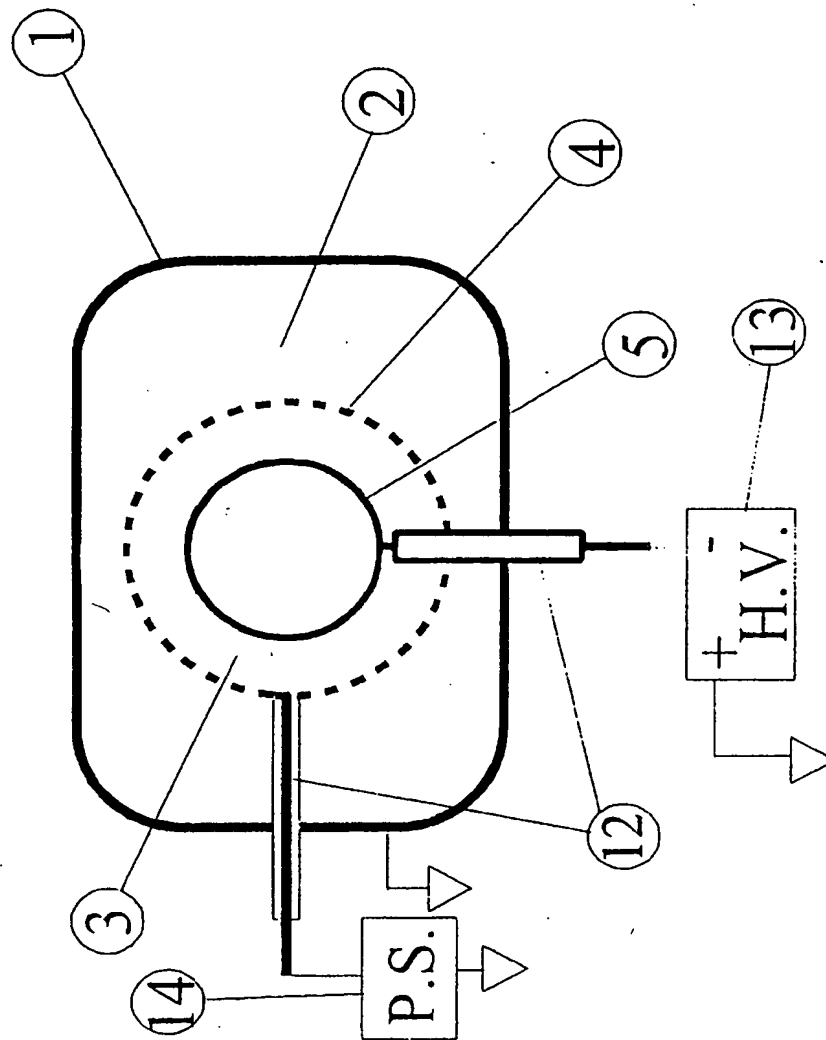
generating a plasma in a first region, said first region partially surrounding a second region;

injecting ions from the plasma in the first region into the second region;

accelerating in a uniform manner the ions injected into the second region towards an object located at a predetermined position in the second region such that all of the ions have the same momentum; and

whereby the ions so injected into the second region are monoenergetic.

6. The method of claim 5, wherein the step of injecting the ions into the second region and accelerating them towards the object comprises the step of subjecting the object to a negative voltage potential.



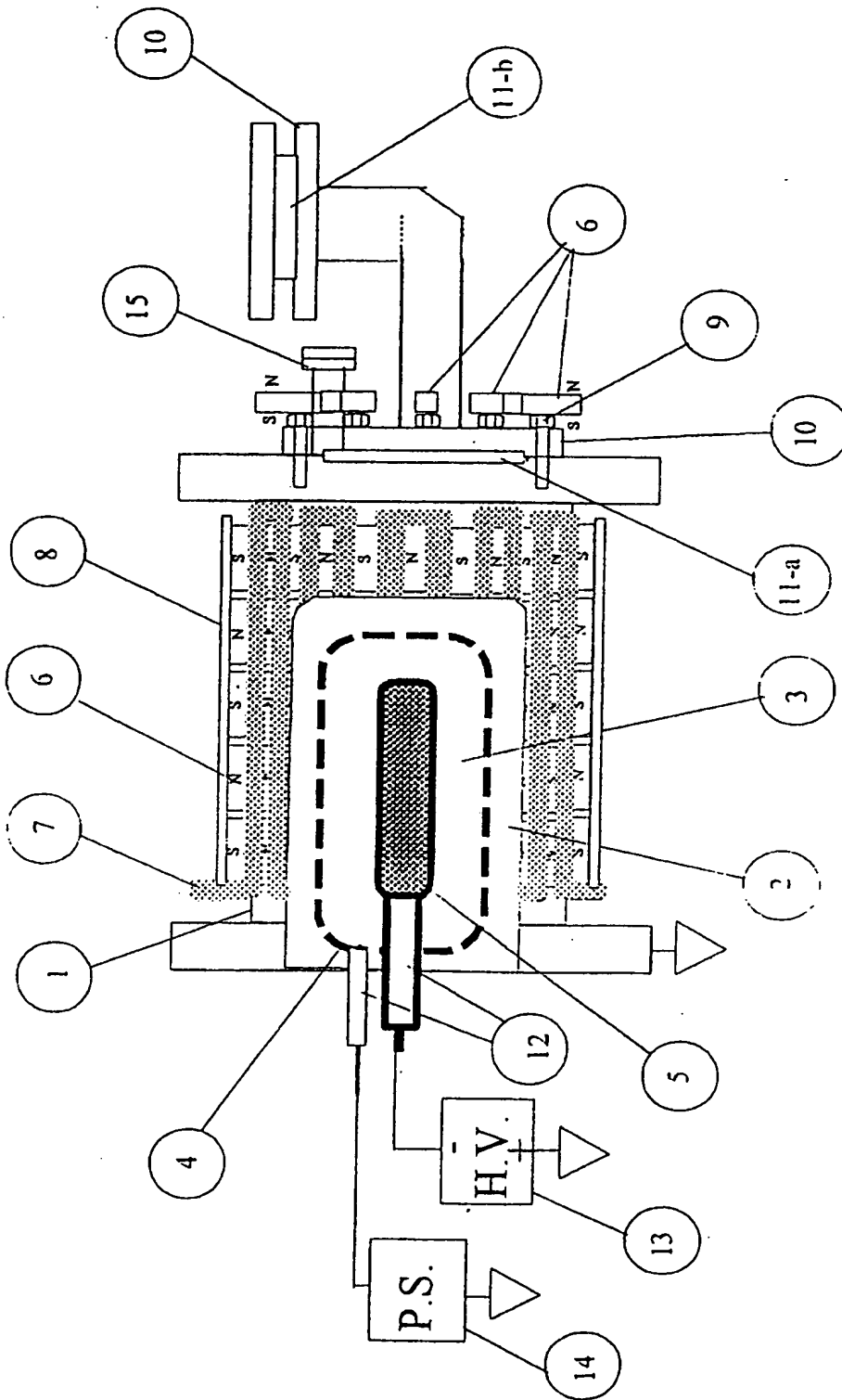


Fig 2

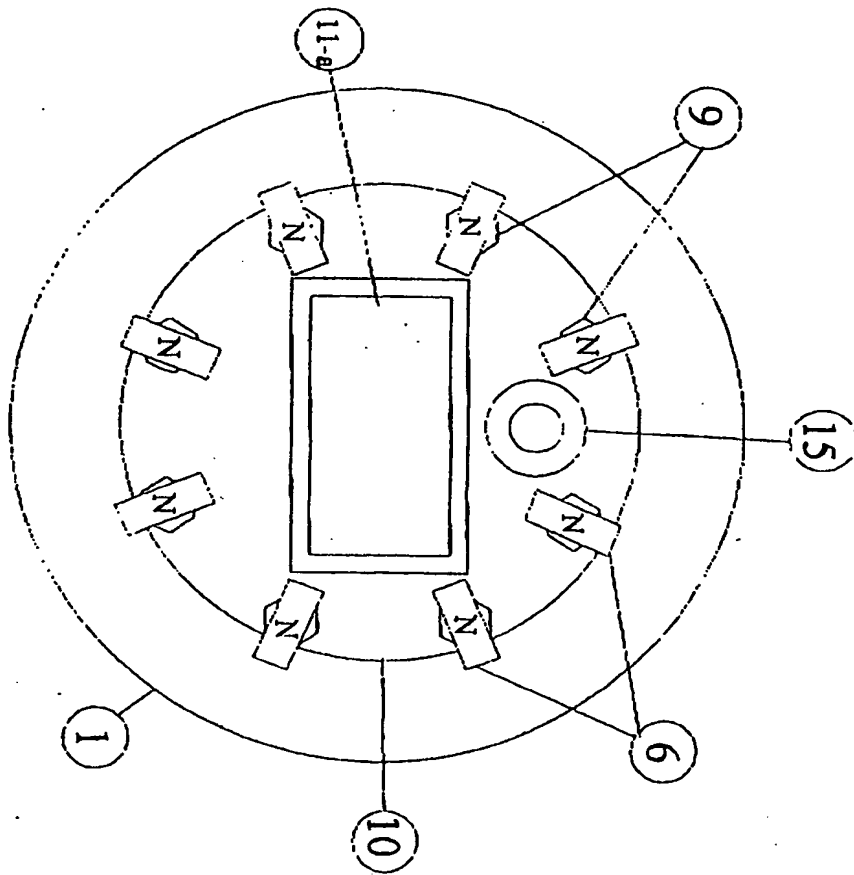


Fig 3



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